Physics of Local Reinitiation and Morphological Evolution of Mitigated Sites for Ultraviolet Optics

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Small defects in laser optics can grow due to exposure to high-power fluence, both degrading the beam quality and ultimately threatening the structural integrity of the optic. Mitigation strategies are under development, yet recent testing of high-fluence operations has revealed ever-more restrictive requirements for the mitigation process. The objective of this work is to develop and implement a predictive, physics-based model to accurately control the mass transport and thermal-induced stress associated with laser-based material processing of high-fluence ultraviolet optics. Mitigated site attributes associated with re-initiation, crack formation, and downstream intensification have been identified that require increasingly sophisticated physics models and experimental programs. The basic material science that governs these attributes is not well understood and lies outside existing current predictive capabilities.

We propose to integrate advanced diagnostics, materials characterization, and fundamental computational capability to clarify the origins and means to minimize or eliminate these effects.

Project Goals

The optics damage mitigation process uses laser-induced heating, melting, and evaporation to remove damaged material, heal subsurface cracks, smooth the surface, and anneal residual stress in the affected region. Development to date has been driven primarily by experimental work supported by empirical models that provide only rough guidance for control of temperature and material transport. Present technology has limited

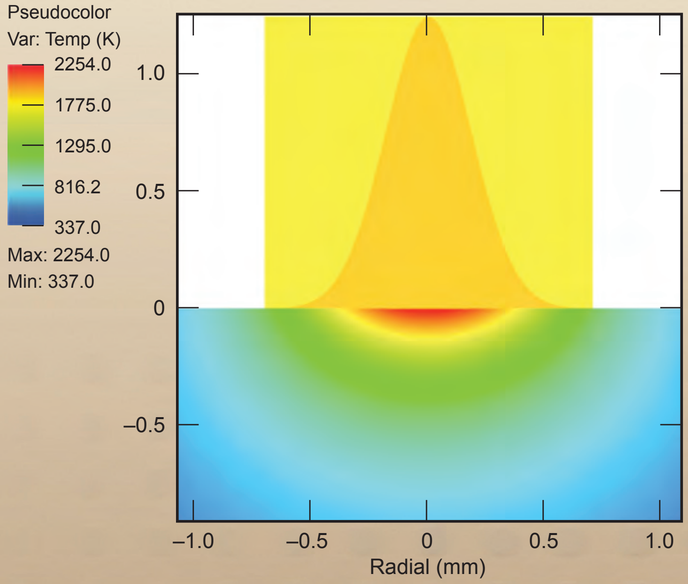

Figure 1. Simulated laser heating of silica with a CO_2 laser. The upper half of the image depicts the Gaussian spatial distribution of intensity within the laser. The lower half depicts a pseudo-color plot of the temperature distribution.

ability to control size, morphology, and damage threshold of a mitigated site, which fundamentally impacts yield and performance. We expect to develop a stronger scientific basis and advanced diagnostics to guide development of mitigation techniques and extend the understanding of laser interaction with optical materials.

Relevance to LLNL Mission

High-energy laser systems are essential tools for the Stockpile Stewardship Program and other national security applications, as well as for inertial confinement fusion as an advanced energy concept. High-energy lasers are also a key scientific element of high-energy-density research at LLNL. This work will provide an enabling technology for these systems to operate efficiently, reliably, and affordably with development of robust ultraviolet-optics mitigation technologies backed by reliable computational models.

FY2009 Accomplishments and Results

We developed an imaging technique to accurately measure temperature (±5%) and thermal conductivity (±10%) of 4.6- and 10.6-µm CO_2 laser-heated optical materials (SiO_2, Al_2O_3, LiF, $MgAl_2O_4$) at spatial and temporal resolutions of 200 µm and 30 ms, respectively. Measured transient temperature maps (Figs. 1 and 2) were in excellent agreement with ALE3D thermal transport models, which included a multi-group diffusion model for radiation transport. Microstructural evolution and residual stress in SiO_2 caused by laser heating above glass transition, were investigated using confocal Raman microscopy, comparing well with predictions from ALE3D. Finally, analytic models derived from a commercial fluid dynamics code were used to predict surface roughness relaxation caused by laser heating on optically damaged SiO_2 surfaces. This work produced three archival journal articles. These results were part of three presentations at an international symposium on laser damage.

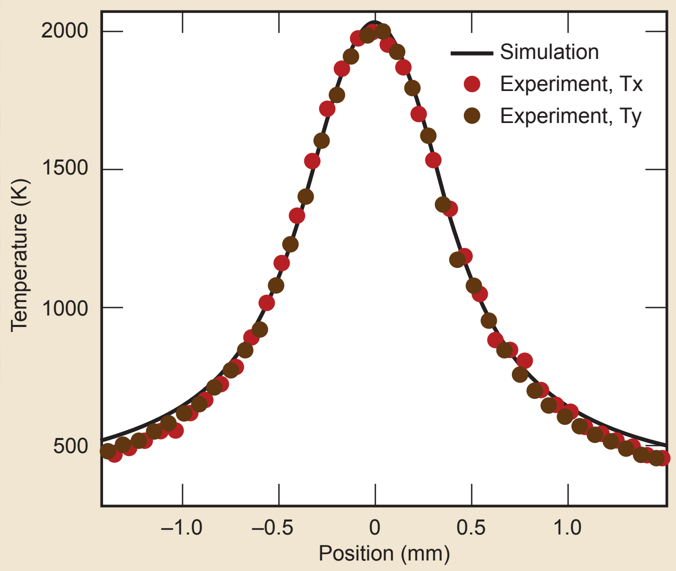

Figure 2. Comparison of simulated and measured surface temperature profiles for CO_2 laser heating of silica. Excellent agreement of the axisymmetric simulation with the data is found for the two orthogonal line-outs.

FY2010 Proposed Work

In FY2010 we will 1) complete our combined hydrodynamics and propagation model connecting visco-capillary surface physics and evaporation on fused silica surfaces to downstream modulation of incident light; 2) develop vapor-phase transport and multigroup diffusion radiation approximations; 3) explore new approaches to mitigation involving active environments and mid-infrared irradiation using our modeling predictions; 4) probe evolution of the glass state and microstructure as it relates to residual defects and stress using characterization techniques such as confocal Raman and time-resolved photoluminescence microscopy; and 5) develop *in situ* diagnostics based on our thermographic probe for potential use in laser mitigation facilities.